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National Implications of High Solar and Biomass Energy Growth: Executive Summary of the Technology Assessment of Solar Energy Project

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by

Gregory J. D'Alessio

U.S. Department of Energy

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PREFACE

This report presents an overview of the benefits and adverse impacts of accelerating deployment of solar and biomass energy technologies between the present and the year 2000 throughout the United States. The conclusions stated here are derived from analytical results of over 40 studies that were part of the Technology Assessment of Solar Energy (TASE) project, which was formulated and directed by the Technology Assessment Division of DOE's Office of Technology Impacts. The TASE analytical study reports are the products of the efforts of dozens of scientists, engineers, and technical analysts from Argonne National Laboratory, Brookhaven National Laboratory, Lawrence Berkeley Laboratory, Los Alamos National Laboratory, Pacific Northwest Laboratory and the MITRE Corp. Their critical comments, ideas, and innovations during the performance of this integrated, national technology assessment have been invaluable. Their efforts have provided numerous insights into the consequences of proposals for accelerated growth of solar and biomass energy technologies. The TASE participants and their project reports are listed in the project bibliography included in this document.

Certain team managers who played essential managerial as well as technical roles in TASE from start to finish deserve special thanks for their performance and for that of their groups. They are Loren Habegger of Argonne National Laboratory; Frederick Lipfert of Brookhaven National Laboratory; Ronald Ritschard of Lawrence Berkeley Laboratory; and Yale Schiffman, formerly of the Mitre Corp.

Thanks are also due to Peter House, now of DOE's Office of Environmental Programs, who approved the initial concept of the study and provided support throughout its duration; to Robert Blaunstein, who guided the development of the solar technology specifications and the community studies; and to Dario Monti and Roger Shull, who continually provided resources throughout their tenures in the Technology Assessment Division.

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ABSTRACT

The Technology Assessment of Solar Energy (TASE) project is a comprehensive multiyear analysis of the environmental, resource, and community impacts which could result in the year 2000 if major national incentives were adopted to accelerate solar and biomass energy use. The study uses a comparative approach to examine (a) the potential impacts of large numbers of solar and biomass units, and (b) the potential reductions in the impacts of new conventional technologies which would be displaced. In addition, TASE examines the indirect pollution impacts associated with the manufacturing of solar systems at greater and lesser rates.

Overall, massive incentives for solar and biomass energy over the next 20 years can lead to major stresses on national capital and finished materials resources as well as to significant air pollution and safety problems. Rapid growth rates for solar systems could markedly increase energy demand in the manufacturing sector. The capital resource and materials problems would arise from emphasis on high, near-term growth of solar technologies, particularly of decentralized active solar systems. The potential environmental and safety problems would arise largely from emphasis on decentralized, uncontrolled biomass combustion.

A range of less costly general approaches lies in greater near-term emphasis on more-mature, competitive technologies and specifically on biomass rather than solar technologies. In particular, this emphasis should be on larger scale biomass units with economical pollution controls rather than on small, poorly controlled units; on safety measures during biomass harvesting; on larger-scale solar technologies that are far less energy- and materials-intensive and hence less costly than smaller solar technologies per unit energy output; and on more-gradual growth rates for active solar energy systems, especially small systems. These measures will help to avoid disproportionate and adverse economic, resource, environmental, and local

community impacts during a transition to a stable renewable contribution to national energy supply.

These findings lead to the conclusions that (a) there are inherent limits to significant, near-term growth in solar energy use in the United States, and (b) certain high biomass energy growth options may be limited by environmental and safety considerations.

1 TASE OBJECTIVES AND ANALYSIS

A technology assessment may be said to examine the unplanned as well as the planned impacts of a technology or technological initiative. This is done by identifying and examining the complete spectrum of potential requirements and impacts of the initiative. The significance of the requirements and impacts is then estimated by comparing them within the context of existing resource requirements and economic and societal problems. In some cases, entirely new potential problems may be revealed by the analysis.

Because of all the possible combinations of analyses, professional knowledge and experience are key factors in identifying a set of analyses which are sufficiently comprehensive yet within the realm of the possible to complete. The key feature of the technology assessment, then, is to reanalyze or critique the features of the original technological initiative. These analyses are done in order that the technological initiative may be redesigned to achieve its goal while minimizing the major unplanned impacts discovered in the set of analyses. In some cases, the result may be complete reconsideration or rejection of the original technology initiative or even its goal.

1.1 IMPACT ANALYSIS

In the case of the TASE project, forty studies were performed over a two-year period by national laboratory analysts to examine the effects of a massive national effort to accelerate commercialization of solar and biomass energy technologies to 12% of the annual U.S. energy supply by the year 2000. These analyses encompassed the potential impacts of such an effort on national resources, on the environment, on community and institutional structures, and on various groups aggregated by job skills and income level. The studies examined the effects engendered by manufacturing solar and biomass systems as well as those which result from their operation. In large part, the study focused on the effects that result from the rapid transition which would be required to bring solar and biomass energy supply to a significant portion (>10 percent) of national energy supply by year 2000. Regional differences in biomass resources, solar potential, and conventional fuel mix in each consumption sector were taken into account, in some cases on a state-by-state basis.

The major analytical efforts fall into four areas:

Technology Characterization and Unit Energy Comparisons: Twenty-six solar and biomass technologies representative of applications in all energy consumption sectors were specified in terms of energy output, materials and operating requirements, and pollutant residuals. An extensive comparison of costs and residuals was made among these systems and with representative conventional systems on a unit-energy-delivered basis. Achievement of 1990's cost and operating goals for the solar and biomass system was postulated.

High and Low Solar/Biomass Growth Scenario Comparisons: Two potential solar/biomass energy futures for the United States in the year 2000 were compared in the context of medium (25%) to high (50%) overall growth in U.S. energy supply requirements. This is consistent with the middle and upper range of current federal estimates (100-118 quads* primary energy). The difference between high- and mid-growth levels is almost entirely attributable to greater or lesser future electricity demand. It is assumed oil and gas consumptions remain roughly constant through 2000. One scenario is a low solar/biomass growth scenario, wherein solar and biomass technologies contribute the equivalent of 6 quads or 5-6% of total national energy supply. This is termed the business as usual (BAU) case and assumes small federal support for solar energy. The other scenario is a high solar/biomass growth scenario where solar and biomass technologies contribute the equivalent of 14 quads or 12-14% of total national energy supply. This is termed the maximum practical growth (MPG) case and assumes large federal incentives for solar energy (see Figs. 1a and 1b).

The renewable technology mix emphasizes solar technologies and hence is consistent with most recent studies. Requirements for natural, capital, and materials resources and changes in pollution levels were examined and compared between these scenarios.

Technology/Scenario Alternatives Analysis: This study examined the changes in scenario requirements and impacts resulting from 15 distinct variations in the solar/biomass and conventional technology mix. Its purpose was to determine how such changes might reduce or increase the level of scenario resource requirements and impacts. In addition to the high penetration rate for solar and biomass systems exhibited in the MPG case (Fig. 1b), a more gradual, low penetration rate was postulated and analyzed in the context of 14 quads of solar and biomass energy in the year 2000.

*1 quad = 10^{15} Btu.

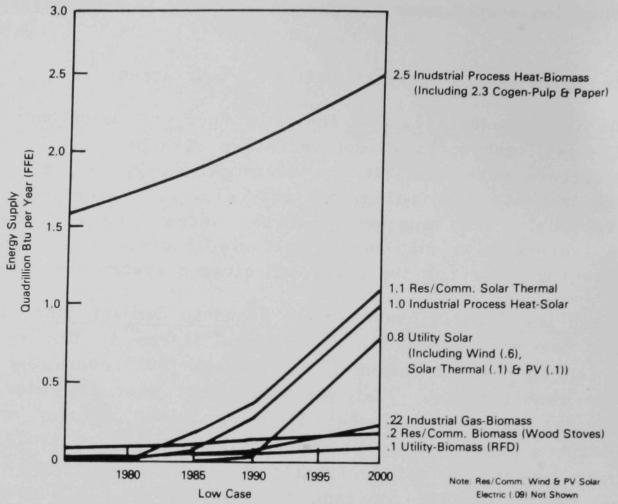

Fig. 1a   Growth of Major Solar Technologies in the U.S.: Low Solar/Biomass Scenario

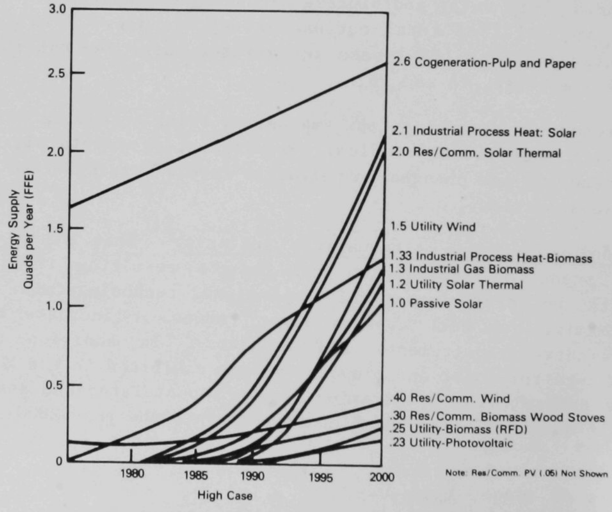

Fig. 1b   Growth of Major Solar Technologies in the U.S.: High Solar/Biomass Scenario

Community and Socioeconomic Analyses: The physical impacts and new institutional requirements resulting from significant use of solar and biomass systems were examined. Also examined were the specific renewable technologies which would be acquired by various income groups and industries and for which job skills would be in greater demand as a result of emphasis on renewable systems.

1.2 INTEGRATED ASSESSMENT

The next step in the technology assessment process involved the integration, synthesis, and evaluation of all significant analytical results. In order to maintain an objective viewpoint, the study attempted to weigh any savings and benefits that might accrue against adverse impacts through the year 2000. The results of this process are discussed in Secs. 2, 3, and 4 of this summary.

This evaluation process also included explicit identification of the critical technological parameters which drive the major impacts (see Sec. 5). From these parameters and a retrospective examination of the original assumptions about the technologies and scenarios, changes in the technologies and scenarios are inferred which would tend to minimize impacts (see Sec. 6).

The introductions to the following sections are cast as questions and answers in order to better convey the general TASE technology assessment process to the reader. The questions are paraphrased below:

- What benefits of accelerated solar and biomass energy growth could result through the year 2000? (Sec. 2)
- What adverse effects could occur? (Sec. 3)
- Do the benefits outweigh the adverse impacts through that period? (Sec. 4)
- What critical features of the technologies influence impacts? (Sec. 5)
- How can adverse effects be reduced? (Sec. 6)

Finally, from this perspective, conclusions are reached about the postulated solar/biomass initiative and its effects, and a general approach to future efforts is recommended (Sec. 7).

2 BENEFITS

Could significant national benefits result from accelerating commercialization of solar and biomass energy technologies? Yes, some benefits could accrue to a significant extent toward the end of the century, primarily from the displacement of conventional fuels and their associated costs.

In order of significance these benefits fall into four categories:

- Conservation of domestic fuels and associated cost savings;
- Reductions in conventional pollution;
- Financial benefits to utilities, certain industries, and certain household groups; and
- Increases in energy sector employment.

2.1 CONVENTIONAL FUEL AND FUEL COST SAVINGS

For the given scenario, significant growth in solar and biomass technologies could offset some growth requirements in conventional fuels. These reductions would be primarily in the growth of coal use and, to a lesser extent, in the growth of nuclear fuel and gas use. In reference to the low solar (BAU) scenario, the contribution from each of these fuel categories to national energy supply would experience a 10-12% drop in the year 2000 in the high solar case. Gas use, which is projected to grow only slightly in the scenario between 1980 and 2000, would be reduced to 1975-1980 levels of use. This reduction may be viewed as a stretching out of domestic resources. Very little oil is displaced by solar unless alcohol fuels are introduced in the transportation sector and greater amounts of heating (solar or wood) displace more residual oil in the residential sector. Even so, opportunities for oil displacement in the year 2000 would not be greater than 5% of overall annual oil use in the high solar (MPG) case. Cost savings, primarily due to coal savings in the high solar scenario, are skewed heavily to the late 1990s. Savings on gross fuel costs for 1980-2000 could be on the order of $400 billion. The potential capital cost savings for conventional facilities that would not be built in the high solar case compared with the low solar case is small compared to potential conventional fuel cost savings and to solar capital cost requirements.

2.2 SMALLER POLLUTION GROWTH RATES

The major environmental benefits would be due to reduced growth in coal mining and to reduced growth in coal combustion. For the year 2000 in the high solar/biomass scenario, up to 200 million short tons of coal per year less might be required nationally. Although coal use would still be increasing in any moderate to high growth (100-120 quads) scenario, this would correspond to 20-25% of 1980 production levels. The reduced annual water pollution associated with the corresponding reduced requirements could be significant. However, the extent and location of such a reduction would depend on conjectures about future coal markets and whether primarily strip mining or underground mining would be displaced. While this was not examined in a specific analysis, the magnitude of the reduction in mining requirement indicates that this would be a major environmental benefit of the high solar/biomass scenario.

Marginal reduction (5%) could take place in primary sulfur and nitrogen oxide levels between the scenarios, but not in particulate levels due to offset by biomass emission. The primary air pollution reductions are not larger because the conventional plants displaced are assumed to be subject to relatively stringent 1985 EPA emission requirements. In the utility sector some 100 large facilities, approximately 60% coal fired and 40% nuclear, are calculated to be displaced. Thus, some 60 rural counties would not be subject to local air pollution in the high scenario that they would be subject to in the low scenario. This is a small number compared to the counties in the nation.

Some minor local benefits might accrue for water availability in the West in the high solar/biomass case. However, in all regions, general water resource requirements were almost completely insensitive to either scenario. This assumes that large biomass energy plantations do not occur.

Similarly, analyses did not reveal any distinct, significant advantages or disadvantages for air pollution or health effects associated with reduced long-range air transport of energy-related sulfates or with long-range transport of biomass-generated particulates.

2.3 FINANCIAL ASSISTANCE FOR UTILITY AND INDUSTRIAL EXPANSION AND FOR CERTAIN CONSUMERS

Utilities would be the primary beneficiary of incentives and subsidies for solar technologies, while industries and agricultural concerns would primarily benefit from the fraction of such financial benefits available for biomass technologies. The extent to which utility customers (whether communities or individuals) and industrial customers might benefit would largely depend on arrangements extraneous to the technologies.

Incentives and subsidies for the direct use of solar/biomass systems in the residential/commercial sector will largely benefit commercial entities and upper-middle-income households. This is due to the basic high cost of residential solar heating and electricity systems. Middle- and lower-income groups will benefit most if subsidies emphasize solar water heating, limited passive design, and wood stoves (preferably with emission controls). Again, the main beneficiaries will be primarily determined by the specifics of the incentives of subsidies.

Unless an almost complete subsidy is assumed, active solar space heating and cooling and certainly residential photovoltaics and wind systems will be limited to upper-income households and commercial entities.

2.4 INCREASED COMMUNITY EMPLOYMENT IN THE ENERGY SECTOR IN THE 1990s

Overall, the high solar scenario would require some 875,000 more direct and indirect or induced employee-years annually for the 1991-2000 period than would the low solar scenario; this is an increase of 23% over the low solar's average annual requirement of 3.75 million employee-years for the energy sector. Of this 875,000 annual employment increase, about 20% is for additional construction, 17% for additional operation and maintenance, and 63% for additional indirect and induced employment (see Fig. 2). Solar energy technologies that require the most direct employment are

- Electric utility, central thermal, and wind systems;
- Medium-temperature, agricultural/industrial, process heat, total energy systems (TES) and residue combustion systems; and
- Residential/commercial heating and cooling, hot water, and wind systems.

Except for the central solar thermal power plants, all of these systems would be widely dispersed geographically. The principal reductions in domestic direct employment under the high solar scenario occur in the construction and operation of coal and nuclear electric power plants and in the mining of coal and, secondarily, of uranium. There will also be minor reductions in employment for the manufacture, construction, and operation of industrial fossil-fuel boilers and fuel-handling equipment; the construction of electric transmission lines; the manufacture of electric machinery and boilers; the manufacture and operation of transportation equipment; and the refining and distribution of oil and gas. Nationally, however, all of these reductions in employment are not of great significance.

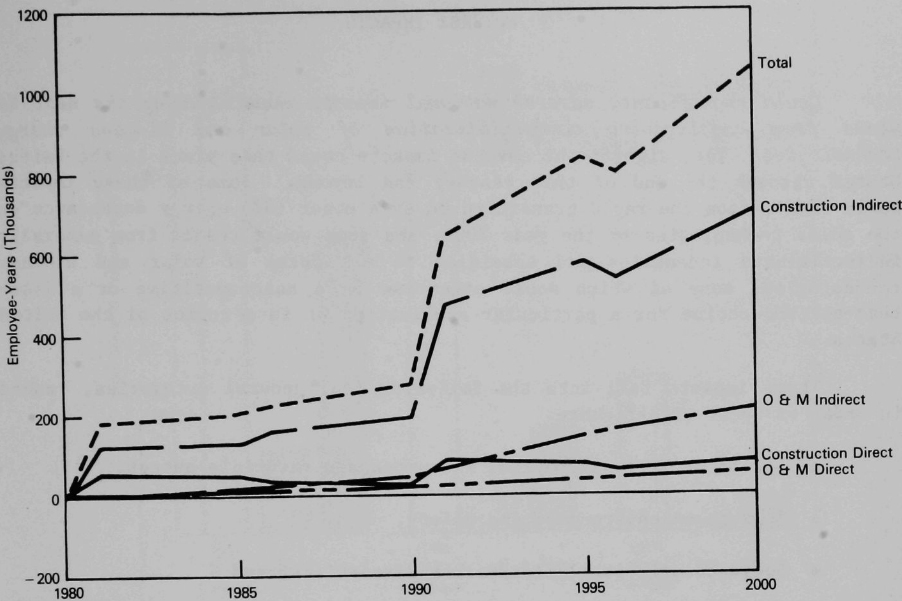

Fig. 2 Increment in Annual Direct Energy Sector and Indirect Manufacturing Employment for the High Solar Scenario Minus Low Solar Scenario

3 ADVERSE IMPACTS

Could significant, adverse national impacts result during the next 20 years from accelerating commercialization of solar and biomass energy technologies? Yes, significant adverse impacts could take place in the United States through the end of this century and beyond. Some of these impacts would result from the rapid transition to even minor (5%) energy dependence on the solar technologies by the year 2000, and some would result from generally indiscriminate incentives and subsidies to all forms of solar and biomass technologies, some of which would otherwise be a noncompetitive or a less-than-optimum choice for a particular application or in a region of the United States.

These impacts fall into the following four general categories, ranked in order of their significance:

- Stress on national capital resources amd materials output,
- Impacts on environment and safety,
- Socioeconomic imbalances/market distortions, and
- Changes in community appearance/burdens on local institutions.

3.1 STRESS ON NATIONAL RESOURCES

In general, stress on national resources derives from rapid growth (over 20-25 years) of energy supplied by the solar (not biomass) technologies to a sizable share of annual U.S. energy supply.

<u>Rapid Solar Growth Leads to Increased Capital, Material and Manufacturing Sector Energy Demand:</u> This stress would manifest itself chiefly as significantly greater (20-25%, or on the order of $300 billion), near-term (next 20 years) capital formation requirements in the energy supply sector when compared with capital investment estimates for more-conventional options to achieve identical national energy requirements. In fact, this stress would begin in the late 1980s and would grow even more intensive through the end of the century. This is due to the fact that solar technologies would be introduced late in the century and are much more materials intensive and thus more capital intensive per unit energy capacity than are conventional technologies. In fact, this would result in solar energy systems manufacturing requiring significant portions (20-25%) of total national finished steel, aluminum, and copper output in the the year 2000 (see Fig. 3). United States dependence on a number of imported strategic materials could increase markedly.

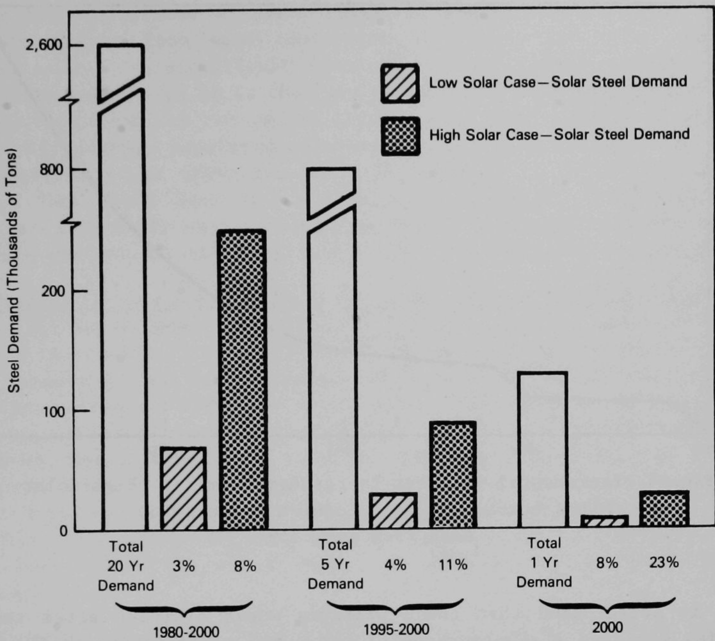

Fig. 3 Comparison of Total U.S. Steel Demand for Solar Systems: Low and High Solar Scenarios

Expansion of the materials and other related commercial industries associated with solar growth would result in even greater secondary near-term capital formation requirements in addition to those in the energy sector.

The direct materials manufacturing requirements would in turn significantly increase the energy demand of the metals manufacturing sector during the period of rapid growth. This could require an additional 1 - 1.5 quads of conventional energy in the year 2000 alone simply to sustain the solar technology penetration rate (see Fig. 4). Furthermore, the more rapid the growth in solar penetration, the greater the growth in conventional energy backup capacity. Thus, during the period of most rapid commercialization (late 1990s and beyond), the net annual solar technology contribution to national energy supply would be 20-25% less than the annual output of national installed solar system capacity.

Overall, greater emphasis on small, distributed solar technology systems would tend to exacerbate these stresses. The distributed solar technologies have greater material, manufacturing energy, and capital requirements per unit energy delivered than do larger solar energy systems.

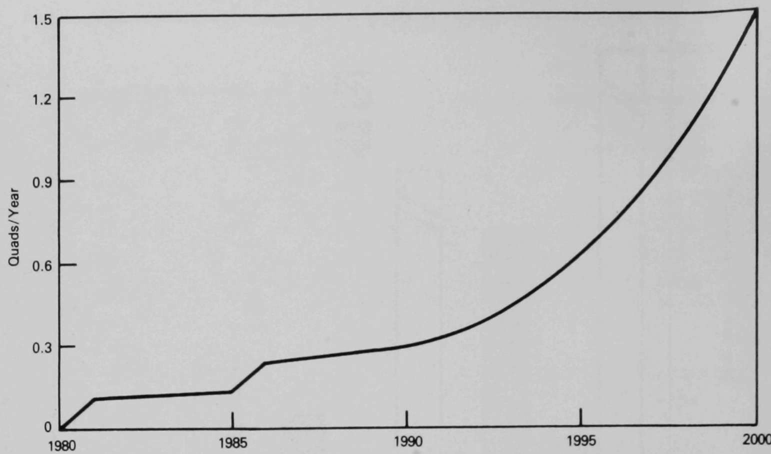

Fig. 4 Incremental Indirect Energy Requirement: High-Solar Minus Low-Solar Scenario/High Penetration Rate (see Fig. 1b)

It is anticipated that these problems would diminish after the solar technologies achieved a stable share of the total contribution to U.S. energy supply. However, this period would likely be no less than 30-40 years from the initiation of rapid growth.

3.2 IMPACTS ON ENVIRONMENT AND SAFETY

In general, the greatest national environmental, health, and safety impacts derived from the collection of biomass and the operation of poorly controlled biomass combustion devices. Indirect pollution from materials manufacturing for solar technologies could be important in a few regions and severe in certain locales.

Biomass Combustion Can Result in Significant National Increases in Particulate Matter Emissions: The major potential environmental impact from biomass is from the emission of airborne particulate matter from poorly controlled combustion (e.g., wood stoves, small boilers, and heat sources). With as little as 2-3 percent of total U.S. energy supply derived from such sources, their particulate matter emissions could approach one-third of the total particulate matter emissions from all energy-sector coal-combustion sources, even though coal would account for one-third of total U.S. energy supply.

Of particular concern are general population health effects which might result from relatively high concentrations of polycyclic organic matter (POM), including benzo(a)pyrene, a known animal carcinogen which is associated with particulate matter from wood combustion in stoves and other small wood-combustion units. A significant fraction of wood combustion emissions from small sources appears to be in the form of fine or respirable particles. This concern is heightened by the recent trend in the concentration of wood stoves in relatively densely populated suburban areas. In addition, such increases in particulate matter emissions would be greatest in a few regions of the country. This could lead to impediments to industrial expansion in those areas where relatively small amounts of poorly controlled biomass combustion would cause ambient air standards for particulate matter to be exceeded.

Biomass Harvesting Can Lead to Regionally Significant Increases in Erosion: The major potential ecological and water quality impact from biomass harvesting is erosion. It is very difficult to quantify the levels of erosion impacts because of the broad spectrum of biomass feedstocks and because such impacts are strongly dependent on locale. However, it does appear that limited collection of certain crop residues, such as those from soybeans and corn, could cause significant increases in agricultural erosion in several agricultural states where erosion is already a serious environmental and resource base problem. While wood would be the primary biomass feedstock nationally, erosion will depend strongly on locale and source (i.e., periodic wood residue collection would result in greater erosion than whole tree harvesting).

Biomass Harvesting Could Result in Significant Increases in Occupational Injuries and Deaths: The occupational impacts of increases in woody biomass collection could be quite large, unless specially managed wood lots and new automated harvesting methods are used, and especially if wood residue collection is emphasized. Present industry statistics indicate that, on a unit energy basis, tree residue removal would result in approximately 50 times the death rate and 75 times the injury rate of underground coal mining. The rates for whole tree harvesting are about one-third of those associated with tree residue removal. Collection of wood by wood stove owners would presumably result in at least as great a rate of injuries and deaths. In addition, deaths associated with operation of wood stoves in the home would increase. In 1980, the operation of wood stoves, which accounted for between 0.5% and 1% of U.S. energy supply, resulted in some 300 deaths.

Growth in Solar Manufacturing Can Lead to Regionally Significant Indirect Pollution: Environmental impacts from the solar technologies are less significant than those from biomass. They are primarily associated with increases in the pollution produced by manufacturing the solar system materials and components. These indirect impacts could be locally and regionally significant during the 1990s, particularly in those locales where steel, aluminum, and copper industries are concentrated. These indirect impacts are associated with increases in atmospheric emissions of sulfur oxide and particulate matter during the period of rapid solar commercialization. They would diminish to a constant annual level after solar systems had achieved a constant market share and required only replacement and maintenance manufacturing.

3.3 SOCIOECONOMIC IMBALANCES/MARKET DISTORTIONS

Because of a solar energy system's high capital costs, general subsidies or tax incentives would tend to directly benefit individuals above middle income, commercial institutions, and utilities. Only wood stoves, solar hot water and limited passive solar measures in certain parts of the United States will be affordable by middle- and lower-income families as well as competitive with other sources of energy without incentives and subsidies. With fairly significant incentives and subsidies, the more sophisticated residential heating and electrical systems would still be largely beyond the reach of those at or below middle income. For upper-middle-income families and above and for institutions, industries, and utilities, subsidies and incentives could favor otherwise noncompetitive applications of solar and biomass in locales where their use would otherwise be inefficient or too costly.

In the case of solar energy systems in particular, artificial subsidies can result in distortions in regional commercialization patterns which would increase materials and energy requirements nationally when compared with a competitive market approach. For example, up to 25% more solar systems are required to provide the same energy output in the north central states than in the Southwest due to lesser insolation and greater cloud cover. Thus, up to 25% more capital and materials would be required nationally to provide this energy by solar systems if subsidies make the price of such systems competitive in the north central area where demand for new energy supplies is great.

3.4 SIGNIFICANT CHANGES IN COMMUNITY APPEARANCE/LOCAL INSTITUTIONAL BURDENS

Community level impacts are basically physical and infrastructural. The main physical impacts are in community land use and in community appearance.

Land Use Impacts: A community can meet the on-site energy demands assumed by the scenario in all but the most dense land-use sectors (e.g., central business district). However, this may require removal of 15-35% of the tree canopy in the residential sector. Further, it may be required that greater than 80% of the total area in the industrial sector and about 50% of the available commercial parking area be covered with solar collectors. Alternatively, additional land would have to be acquired at considerable cost.

Building and Urban Design: Although passively designed buildings in future residential, commercial, and industrial sectors need not look different from existing versions, the overall appearance of a community with a high level of solar development (e.g., large collector areas and tree removal), may be quite different based on current urban design and aesthetic criteria.

The main infrastructure impacts are potentially significant changes in private/government relationships and in the complexity of energy planning at the local level.

Institutional Impacts: Various institutional impediments produce delays in achieving acceptance of solar technologies within the community structure. Most important among those barriers are the acceptance and adoption of solar by residential and commercial building industries, the legal issues of solar access, easements and use of public lands for solar technology installations, and the aesthetic concerns of the public and planning agencies. In order to meet the levels of on-site solar collection that are described in this study, these impediments would have to be removed, presumably by government.

Community-Level Planning: There are opportunities for implementing decentralized solar technologies within a community. However, implementation will require the integration of urban and energy planning at the local level in order to avoid potential aesthetic, institutional, and land use impacts. This level of planning exists only on a limited level in U.S. communities.

4 NET EFFECTS

Do the potential benefits of an enhanced level of solar/biomass energy supply driven by broad general incentives and subsidies justify the costs by the turn of the century? No; in achieving the same national energy supply as more conventional energy paths, the overall adverse impacts of an accelerated solar/biomass (approximate 60-40 ratio) technology commercialization program outweigh the potential benefits over the next 20 years on a national basis.

The results of the evaluation of advantages and disadvantages of accelerated solar/biomass growth are summarized in four categories:

- Higher national financial and critical resource costs for largely noncritical fuel savings;
- No clear net national environmental advantages and some potential net health and safety problems;
- Possible uneven distribution of incentive benefits leading to potentially less efficient, less competitive applications; and
- Increased near-term workload burden on community government and institutions could defer potential local energy and employment benefits.

4.1 HIGHER COSTS FOR NONCRITICAL SAVINGS

<u>A Small Solar Energy Increment Requires a Large National Resource Commitment:</u> The most significant impacts are associated with greater near-term primary and secondary capital resource requirements. Costs would rise sharply through the 1990s with continuing and significantly greater growth in production requirements for finished steels, copper, and aluminum. If the latter are assumed to be imported, balance of trade impacts arise along with concerns about interruption of supply.

<u>Solar Capital and Operation and Maintenance (O&M) Costs Outweigh Fuel Cost Savings:</u> The annual fuel savings and associated cost savings benefits associated with accelerated dependence on solar and biomass technologies become large near the year 2000. However, on a national basis they would not begin to offset national capital investment and O&M expenditures for solar systems for at least 20-25 years after the start of rapid solar growth, even for more gradual growth rates than assumed in the MPG case (see Fig. 5a). The cost growth associated with Fig. 1b (MPG case) is shown in Fig. 5b. Furthermore, rapid growth rates in solar technology manufacturing can markedly

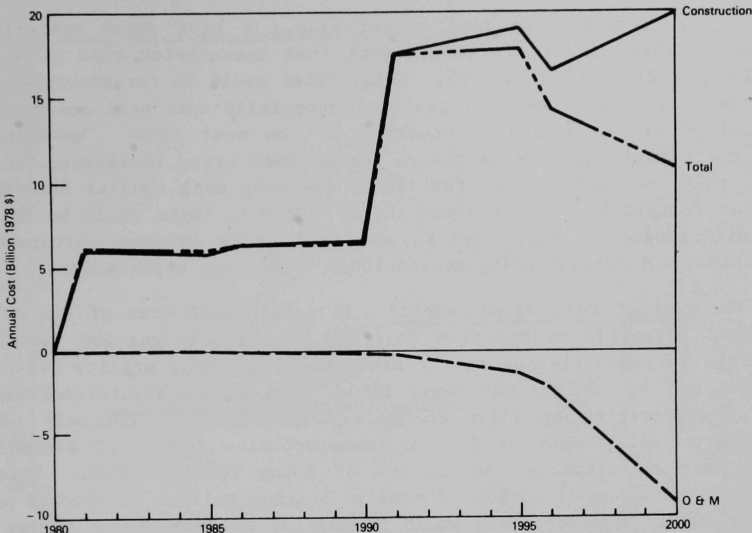

Fig. 5a Scenario Cost Difference: High-Solar Minus Low-Solar Scenario/Low Penetration Rate MPG Case

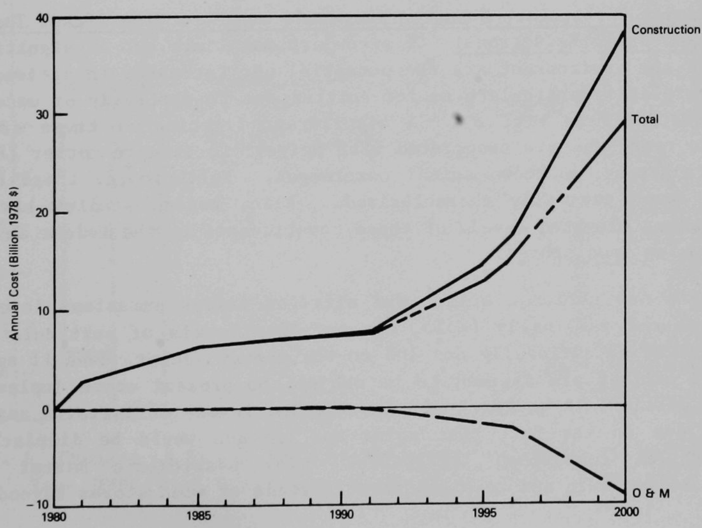

Fig. 5b Scenario Cost Difference: High-Solar Minus Low-Solar Scenario/High Penetration Rate MPG Case (see Fig. 1b)

increase energy demand in that sector (i.e., a high solar scenario would require a greater level of conventional fuel consumption than shown in the scenario to reflect this factor). This period would be foreshortened only if increases in the price of oil, gas, and especially coal well above currently projected mid-level estimates occurred in the near term. However, solar system costs would also reflect such marked fuel price increases. Displaced capital costs of conventional facilities are very much smaller than costs of the solar facilities which replace them. However, there could be relatively small differences in both capital and fuel costs between certain biomass applications and corresponding conventional technology applications.

Noncritical Fuel Displacement: In particular, most of the displaced fuel would primarily be domestic coal and secondarily gas and uranium, not oil. This is primarily due to the assumption that most utility oil use will be backed out by coal by the early 1990s, well before significant displacements of electricity by solar energy can take place. The only potential exception of note could be in the transportation sector if alcohols from biomass were to displace up to 10% of motor fuel by 2000. This would correspond to an annual output of some 10 billion gallons of alcohol per year for year 2000. However, this would be only 1% of anticipated energy supply and only 3-5% of total projected petroleum energy requirements.

4.2 NO NET ENVIRONMENTAL ADVANTAGE/HEALTH AND SAFETY PROBLEMS

Biomass Particulate Emission Increases Are More Significant Than Sulfur and Nitrogen Oxide Reductions: Of secondary magnitude but of significance to health and the environment are the potential net increases in national levels of energy-related particulate matter emitted due to partially or uncontrolled wood combustion (see Fig. 6). A significant fraction of these are in the respirable range and are associated with polycyclic organic matter (POM) such as benzo(a)pyrene, a known animal carcinogen. Furthermore, these emissions have only been partially characterized. Also, recent studies have raised concerns about elevated levels of these constituents in the indoor environment of homes using wood stoves.

While net national sulfur and nitrogen oxides emissions levels could each be reduced marginally (<5%), net emission levels of particulate matter could increase 3% nationally and 10% in the energy sector, even if small wood industrial boilers are assumed to be subject to present state implementation plans for particulate matter control. The low levels of emission savings are partially due to the fact that solar and biomass would be displacing new, well-controlled combustion facilities. The particulate matter emission increases do not even assume significant inroads of wood stoves beyond present levels.

On this basis, acceleration of solar technologies cannot be viewed as a cost-effective, indirect means of reducing national air pollution levels when compared with direct investments in control technology.

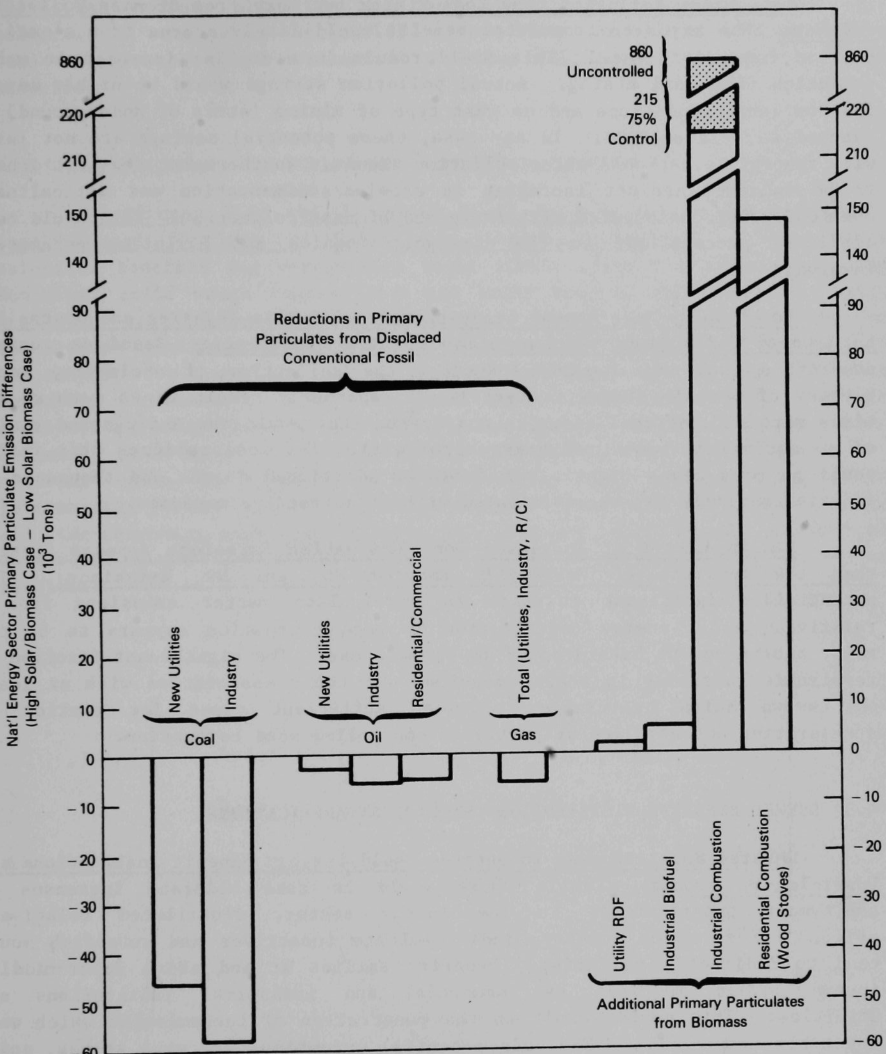

Fig. 6 Changes in Direct Particulate Emissions by Source Category: Year 2000 (High Solar Scenario Minus Low Solar Scenario)

Less Water Pollution from Coal Mining but More from Biomass Collection and Use: The major environmental benefit would likely accrue from a smaller coal mining growth rate. This would result in a smaller increase in water pollution from coal mining. Actual pollution savings would be highly dependent on local conditions and on what type of mining (strip or underground) is assumed to be displaced. In any case, these potential savings are not large with respect to national water pollution trends. Furthermore, they would have to be balanced against increases in erosion/sedimentation and agricultural chemical runoff associated with increased biomass collection. This would be a difficult process due to the divergent locales and pollution parameters involved.

Potentially More Annual Occupational and Public Injuries and Deaths Due to Biomass Collection vs. Conventional Energy Incidents: Based on current statistics from the logging industry, the collection of whole-tree woody biomass of certain energy content would apparently result in as much as ten times more occupational injuries and deaths than would the underground mining of an equivalent amount of energy from coal. For wood residues this factor could be many times higher. Hundreds of additional deaths and thousands of injuries annually may be anticipated without corrective measures.

Health Hazard of Increased Wood Combustion Emissions Appears Greater than the Benefits of Marginally Reduced SO_2 and NO_x Emissions: The potentially significant increase in particulate matter emissions from a relatively small energy contribution by wood combustion appears to be the major public health hazard posed by biomass use. The significant fraction of respirable particles in these emissions and their association with at least one known animal carcinogen provides sufficient cause for caution in accelerating uncontrolled or partially controlled wood combustion.

4.3 SKEWED BENEFITS DISTRIBUTION/INEFFICIENT APPLICATIONS

General Solar/Biomass Incentives Could Largely Benefit Institutions and Upper-Income Groups: While there would be some moderate increases in employment opportunities in the energy sector, distributed relatively uniformly across the country, indiscriminate incentives and subsidies would tend to indirectly and chiefly benefit families at and above upper-middle-income levels as well as commercial and industrial institutions and utilities. This could result in the penetration of technologies which were not truly competitive. The only potential exceptions are wood stoves, solar hot water heaters, and limited passive design. All of these would be competitive and available to low- and middle-income groups by the early 1990s.

The greatest beneficiary of solar technology subsidies could be the utility industry. Such subsidies, when combined with inherent advantages of scale, could greatly expand the use of large wind machines and solar thermal power systems, but possibly into otherwise noneconomically attractive regions. The main beneficiary of biomass technologies subsidies could be the industrial sector, primarily pulp and paper, food processing, and agriculture. In some cases the subsidy of less than competitive applications can lead to resource and environmental problems which would not have otherwise occurred.

4.4 INCREASED NEAR-TERM BURDEN ON COMMUNITY INSTITUTIONS

Significant Time and Resources Would Be Required to Alter Community Institutional Barriers to Solar and Biomass Technology: The greatest potential benefits for communities would likely arise from moderately sized municipal solid waste cogeneration and solar thermal units matching energy needs for neighborhoods, shopping centers, or apartment complexes and from associated construction employment. Modest local employment opportunities associated with operation and maintenance of these systems would also be expected. However, the financial, institutional, and legal barriers to such applications of large numbers of distributed systems are ingrained in current community attitudes, ordinances, and infrastructures. To alter these on a national basis throughout the approximately 3,070 counties and 80,000 governmental jurisdictions of the United States would be a monumentally costly and time-consuming task. Significant penetration by solar in the residential/commercial sector of communities will not likely occur before these issues are resolved.

5 CRITICAL CHARACTERISTICS

What characteristics of solar-biomass technologies are critical to determining national impacts? The impact critical characteristics of these technologies can be divided into two categories: those which are intrinsic to the technology (i.e., solar/biomass system) and those which are intrinsic to the deployment of the systems.

5.1 TECHNOLOGY

Solar System Materials and Imbedded Energy: These factors are the primary drivers of high resource and cost requirements. Alternate materials which require less manufacturing energy would be required to mitigate this problem. Economy of scale is a significant facet of this issue, with larger scale systems generally requiring less resource per unit energy output.

Solar System Performance and Life Cycle Characteristics: This includes the system efficiency which is the focus of much effort and attention. Less attention is generally paid to the critical factors of system lifetime, availability, replacement requirements and performance degradation with time. All of these factors can radically affect the estimates of system life cycle cost. The TASE characterizations and cost estimates imply optimistic values of all these parameters when compared with presently available systems. Material and system design are important facets of these characteristics.

Biomass Process Pollution Control: Control of liquid effluents from bioconversion and most particularly control of particulate matter from biocombustion are mitigating factors for environmental impacts. Scale of a biomass facility is critical to this issue because control technologies are economical in terms of overall system operation only for medium- to large-scale facilities. Conversely, small-scale facilities are less likely to have such controls.

5.2 DEPLOYMENT

Definition of Application Requirements and System Selection: This factor refers to the level at which an application need is defined. For example, will the application requirement for heating a community be defined by individuals (select many residential systems) or by community planners (select many residential systems or one or more larger scale systems). The level at which this planning is done can thus have important aggregate resource and cost implications at the community and national level, again largely due to economies of scale and to certain efficiencies attainable with large-scale storage and central distribution. In general, this requirements definition can only be done at the local level. Note that subsidies can skew the system selection process toward more resource-intensive technologies which would normally be noncompetitive.

Biomass Harvesting Pattern and Methods: This will drive bioconversion process selection and hence pollution characteristics. It also drives feedstock selection and hence, along with local conditions, erosion/sedimentation severity. Collection method along with local characteristics will determine occupation incident levels.

Penetration Rate: This rate critically drives solar materials resource requirements and related manufacturing, or indirect, pollution. National costs are closely related to this rate. Figures 7a and 7b show the difference in direct, indirect and net particulate matter emissions between the low and high solar/biomass scenarios for different penetration rates. Figure 7a corresponds to a sensitivity study where a more gradual growth rate for the MPG case is postulated. Figure 7b corresponds to the basic MPG case growth rates shown in Fig. 1b.

Technology Mix: This includes the ratio of solar to biomass technologies which roughly indicates relative cost and resource intensity vs. environmental impact intensity; and the ratio of decentral to central technologies which is indicative of greater resource and cost intensity for solar and greater potential pollution impact for biomass. The geographical and economic sector patterns of this mix can also markedly affect overall impacts and costs.

External Factors: Clearly, incentives which target specific technologies or applications can affect the mix. Conventional fuel displaced by a solar/biomass initiative can affect emission savings (e.g., displacing natural gas has little environmental benefit).

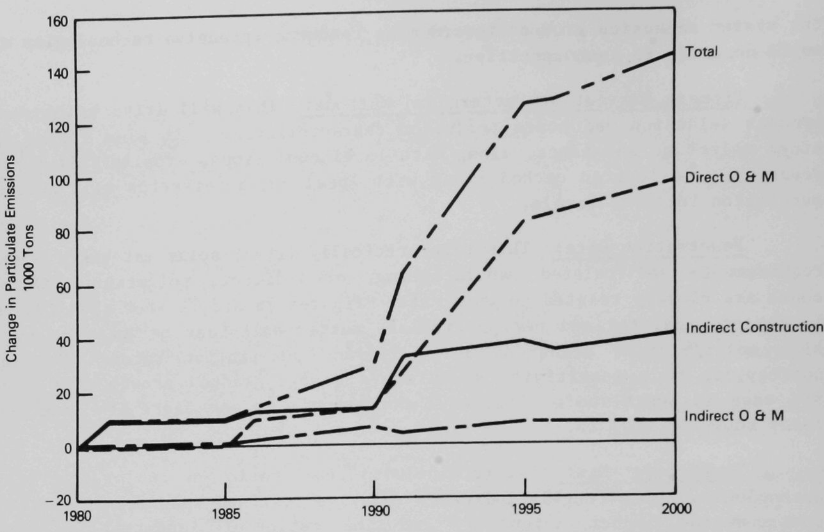

Fig. 7a Incremental Particulate Matter Emissions: High-Solar Minus Low-Solar Scenario/Low Penetration Rate MPG Case

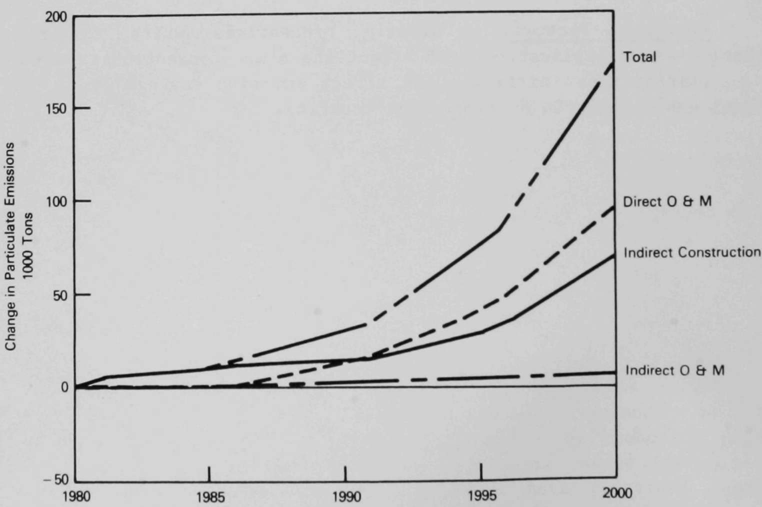

Fig. 7b Incremental Particulate Matter Emissions: High-Solar Minus Low-Solar Scenario/High Penetration Rate MPG Case

6 MINIMIZING IMPACTS

How could national resource requirements and impacts be minimized during the growth of the solar/biomass energy market share over the next 20 years? In general, resource impacts and indirect pollution can be avoided only by reducing emphasis on most of the solar technologies considered and by focusing on the few solar technologies expected to be cost effective, that is, not so resource intensive. Environmental, health, and safety impacts can only be avoided by selection of those biomass technologies which are controlled or are low emitters of residuals; by carefully selecting biomass feedstocks and areas which have relatively small pollution potential; and by using safe and/or automated harvesting methods.

There are two general implications of this during the next 20 years:

- limits to solar growth; and
- limits to biomass pollution or limits to biomass growth.

6.1 LIMITS TO SOLAR GROWTH

Technology Options Few: There are limits to the growth of solar technologies at levels not far above "business as usual" expectations due to the relatively small number of appropriate solar technologies and nonsubsidized competitive applications. Passive design, solar hot water heating, low temperature process heat, utility wind and thermal systems each appear to be in competitive ranges but only in certain locales of the United States. Much more efficient, longer-lived systems are extremely unlikely to be available for commercialization by 2000.

Growth Rate Low: Capital and material resource stresses can only be reduced by a more gradual solar growth penetration rate targeted to more modest levels of energy supply than shown in Fig. 1b. Should incentives stimulate such stresses, strains on capital availability and increased materials prices may be expected.

6.2 BIOMASS POLLUTION VS. BIOMASS GROWTH

Control Options: In order to avoid significant emissions of particulate matter from biomass combustion in a cost-effective manner, larger industrial combustion units with cost-effective pollution controls appear necessary if biomass is to expand its role. Pollution controls for stoves exist, but at a high fraction of stove cost. Cogeneration from wood waste may offer the highest potential.

Some of the bioconversion processes examined may be more competitive (and environmentally acceptable) if their feedstock is the waste product of an economically viable enterprise.

Controls on the process heat units of bioalcohol production facilities are necessary to reduce potentially high annual emission loadings from a large number of such facilities.

Less emphasis on tree residue and crop residue harvesting will minimize potentially high occupational hazards and excessive erosion.

Trade-offs: At the levels examined, biomass penetration does not appear to be resource (feedstock) limited. Furthermore, some biomass technologies appear to be approaching a range competitive with certain conventional applications. This is especially true of biomass combustion.

However, should uncontrolled or minimally controlled biomass systems expand as a result of incentives, environmental regulatory mechanisms may be expected to impede further expansion. Should controlled systems be emphasized, local biomass resource cost, availability and sustainability would be major limiting factors.

7 CONCLUSIONS AND AN APPROACH TO THE FUTURE

Any near-term national renewables commercialization effort which avoids major, adverse national impacts must focus on the limited number of relatively mature, reliable technologies which present competitive applications in specific economic sectors in particular areas of the United States.

The long-term (50-100 year plus) net benefits, and indeed the necessity, of increasing reliance on a more diverse combination of energy technologies rather than on a few which depend on ever more costly, ever diminishing fossil fuels are axiomatic, if present U.S. population levels and relative economic well being are to be maintained or exceeded. Nonetheless, the near-term impacts of a transition to such energy technology options must not be neglected through emphasis on their long-term contribution to a stable energy supply.

7.1 NEAR-TERM OPTIONS

Solar: The net near-term disadvantages of an accelerated national commercialization program for solar technologies driven by broad incentives and subsidies appear to be so great compared to more conventional alternatives, as to cause this option to be nationally impractical in the near term.

Significant advances in efficiency, reliability, and life expectancy beyond those projected for the 1990s for most solar systems would be required to make most of the systems studied cost effective. Relatively little research and development (R&D) has been devoted to the latter two critical areas. Such efforts would largely involve low-cost materials studies as opposed to more exotic means to increase efficiencies.

Biomass: Resource problems are less limiting for biomass in general. However, unless biomass processes which control emissions are emphasized along with feedstock and collection methods which minimize erosion, resource depletion, and potential safety problems, disproportionate environmental impacts can arise with marginally increased biomass utilization. In the near term it appears that biomass use could dominate solar use in the United States.

Deployment: A more gradual (BAU) solar growth rate associated with the more competitive solar systems (hot water; passive solar; low temperature process heat; large utility wind systems) is indicated. This could be coupled with a more rapid but selective near-term growth in biomass utilization which emphasizes controlled combustion by large units in the industrial sector and which gives some attention to biogas and bioalcohols. This appears to be the best strategy for increasing the contribution by renewable technologies to U.S. energy supply in the year 2000 with a minimum degree of adverse national resource, environmental, and socioeconomic impacts.

7.2 MID-TERM OPTIONS DEVELOPMENT

R&D: It appears that the following directions for research would assist in expanding cost-effective renewable energy options:

- Focus solar R&D not only on improving system efficiency but also on greatly improved system reliability and lifetimes through the use of alternate but less costly materials and innovative system designs.

- Focus biomass R&D on processes and on feedstocks selection/collection methods which are inherently less polluting or which are amenable to cost-effective pollution control development.

- Develop system engineering approaches to match system performance criteria with the most cost-effective scales for applications (i.e., residential, neighborhood, community, or utility scale) in the selection of renewable systems. This portends opportunities for efficiency and associated cost savings if local or institutional planners possess and use such an approach.

7.3 LONG-TERM EXPECTATIONS

The development of additional, mature, cost-effective solar and biomass technology options will require resources, ingenuity and time.

Furthermore, past experience has demonstrated that all mature energy sources and technologies require many decades to achieve a sizable, stable contribution to total national energy supply.

The potential near-term national resource and environmental consequences of ignoring these technological and economic realities demonstrate that there is neither a near-term shortcut nor a long-term easy path to realizing even moderate national contributions from solar and biomass energy technologies.

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